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FEASIBILITY DEMONSTRATION OF A FOUR-PANEL ENVIRONMENTAL SIMULAT--ETC(U)
SEP 78 R D ULRICH, H C SCHAFER N00123-72-C-1704

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Feasibility Demonstration of a Four-Panel Environmental Simulation Oven

by
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Brigham Young University
and
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Range Department
for the
Ordnance Systems Department

SEPTEMBER 1978

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Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

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FOREWORD

This report describes a new type of simulation oven consisting of four independently controlled heating panels. This work was done during the period 1 June 1972 to 1 June 1973 at Brigham Young University. Dr. Richard D. Ulrich was the Principal Investigator. The effort described herein was sponsored by the Naval Weapons Center (NWC), China Lake, California, under Navy Contract N00123-72-C-1704 and support by the Naval Air Systems Command under AirTask A3303300/008B/2F31330300.

Mr. Howard Schafer was the Navy Technical Coordinator and co-author and has reviewed this report for technical accuracy.

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Ordnance Systems Department
1 July 1978

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(U) *Feasibility Demonstration of a Four-Panel Environmental Simulation Oven*, by Dr. Richard D. Ulrich, Brigham Young University, and Howard C. Schafer, Naval Weapons Center. China Lake, Calif., Naval Weapons Center, September 1978, 26 pp. (NWC TP 5965, publication UNCLASSIFIED.)

(U) The object of this study was to demonstrate the feasibility of producing a test chamber which could reproduce a temperature distribution within a rocket motor (as a function of time and position) as is produced by the sun as it radiates energy to solid propellant rockets stored out-of-doors and as it moves through the sky. This project discusses the design problems in such a system, presents results of testing, and indicates that, indeed, such a test chamber is feasible.

CONTENTS

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The authors wish to express their appreciation to Mr. Robert Baird and Mr. Hugo De Campos (graduate students at Brigham Young University) for their contributions to this investigation.

INTRODUCTION

CURRENT FORCED CONVECTION OVENS

A good forced convection high-temperature chamber is, for all intents and purposes, temperature gradient-free in all three directions in the test volume. The 20 x 8 x 8 feet (6.1 x 2.4 x 2.4 m) chambers at China Lake, for example, are gradient-free to about 1/16 inch (1.6 mm) from the wall even during cam-controlled cycling. This is because the air inside the chamber is circulating at a velocity much higher than 25 knots.

Since the forced convection chamber is gradient-free, the same amount of heat will, in general, penetrate anything positioned in that chamber at a normal angle on all surfaces at once. Or it can be said that the test item is being heated as if the sun were shining directly on and all over the item at the same time (i.e., top, bottom, east, west, north and south sides). Obviously the amount of heat entering or leaving the test unit under these conditions is very much different from that occurring during field exposure. The question that should now be of vital concern to the test community is what do we do about it?[1]

One large step forward was replacing the single-temperature soak with a cam-following temperature-controlled profile. Thus, instead of 8 hours at 160°F (71.1°C), followed by 16 hours at -65°F (-53.9°C), some type of constantly varying temperature profile could be imposed on the item during that 24-hour test period. One question, however, was not addressed: would the physics of the situation allow the unit under test to respond as it would in real life? It is true that the cam controller can maintain chamber temperatures exactly identical to the temperatures experienced at some single location on the test unit during a given field exposure day, but it also subjects all other surfaces of the unit to the same exposure pattern. This then leads to the question: is it temperature alone or temperature and heat rate into the item that is really important?

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[1]Schafer, H.C., *Deficiencies in Traditional High-Temperature Storage Testing*, J. of Environmental Sciences: Vol. XX, No. 1 (Jan-Feb 1977), p. 15.

By making a simple comparison, we can quickly determine the general answer to this question. Using the field-measured thermal response data of the test unit as the "standard," we can compare the chamber-induced and field-induced response data for the test unit. In a forced-convection situation the heat rate (q) is proportional to the differences in temperature (ΔT). The constant of proportionality is usually broken down into two functions, area (A) and a description of the way the air (or wind, h) is forced over the test unit by the chamber fans. Now, by loosely equating the field-measured ΔT with that initially imposed by the chamber, some insight can be derived into what may need to be done with present forced-convection chambers to more faithfully reproduce field-type exposure testing.

Concentrating on the area (A) and wind (h) terms, the in-the-field area of exposure can be thought of as only one side of an item at a time, when normal insolation is even nominally available. For our purposes, this one side will equate to A = 1 for the field. But, if this same box is in a forced-convection, gradient-free chamber, the area of normal exposure for maximum heat penetration is no longer just one-side but, rather, all six sides at once or A = 6. All other factors being equal, it is evident that the heat rate into the test item in the chamber will be six times greater than it would be in the field. Remember, though, that the air flow factor (h) has yet to be considered.

In field measurement experience, the maximum wind velocity on a hot day is generally less than 4 or 5 mph (6 or 8 kmph), representing a value of h between 1/2 and 1. Conversely, the value of h for forced-convection chambers is between 5 and 10. Therefore, an evalu[illegible] both h and A at equal temperatures indicates that heat rate int[illegible] test item in the chamber may be between 30 and 60 times greater th[illegible] field heat rate. This example indicates that even our present day, e[illegible]lightened, cam-controlled tests are at least one order of magnitude too severe.

Traditional chamber testing also changes the test unit's thermal time constant of response. Since heat rate into the unit is so much greater than would occur in nature, the thermal mass of the item cannot act to slow down temperature changes as it would under natural extreme circumstances. In fact, in one early investigation, a 6-inch- (152.4-mm-) diameter spherical thermal standard, a box of 50-caliber ammunition, and an inert CBU-55 liquid-filled weapon weighing about 500 pounds (226.8 kg) were put into a forced-convection chamber at the same time. The oven was selectively cam-controlled to the response measured in the field on each item. The thermal standard[2] and 50-caliber ammunition, as well as most

[2] Naval Weapons Center. "Evolution of the NWC Thermal Standard, Part 1. Concept, Part 2. Comparison of Theory with Experiment, Part 3. Application and Evaluation of the Thermal Standard in the Field," by R. D. Ulrich, China Lake, California, NWC. Part 1, February 1970; Part 2, August 1971; Part 3, June 1977 (NWC TP 4834, Parts 1-3, publication UNCLASSIFIED.)

of the 500 pound (227 kg) CBU-55 sensors, responded either the same or very similarly. In other words, the thermal time constant of response of these thoroughly different items, regardless of mass, was so reduced that, in essence, they thermally followed the forcing chamber temperature. In no case were the thermal gradients through these items anything like those measured in the field. There was no correlation of measured responses from the centers of these units to those experienced in "nature."

This test then demonstrated that something other than just air temperature control was necessary in an oven test; thus indicating a need for a combined time-varying-radiation and convection oven. That is, an oven which simulates the solar radiation heating (magnitude, if not wavelength) of the ambient air. The feasibility demonstration of such an oven was the object of this effort.

In order to study these temperature variations, it is necessary that an "oven" accurately reproduce the temperature distribution within the rocket which it had attained in nature. For this demonstration, it was decided to use a liquid as the direct source of heat for radiation to the rocket. A test chamber was constructed having four panels, as shown in Figure 1. Each panel represented a direction of the sun with respect to the rocket, i.e., east, west, top, and bottom. The fluid (water + glycol) was heated by remote electric waterheaters and then circulated through the respective sides. The temperature of the fluid going to each panel was independently controlled. Results of testing indicate that this environmental simulation test chamber does indeed reproduce the temperature distribution within the rocket as if it were exposed to the sun's radiation.

APPARATUS

A four-panel oven was designed, built and tested to demonstrate the feasibility of the type of oven needed. A close-up end-view of the oven is shown in Figure 1. The diamond shape is the opening into which a rocket motor is placed. Each side of the oven is a panel (about 1 x 3 feet) (0.3 x 0.9 m) of aluminum painted with dull black paint. Each panel is heated, using an independent heater inside a 15-inch (381-mm) section of 2-1/2-inch (63.5-mm) pipe (under the operator's left hand in Figure 1), by circulating a water-glycol mixture through a serpentine channel cut in the insulating plate behind the aluminum. The heated water-glycol mixture was circulated by a constantly driven, positive displacement pump.

Electric panel or quartz lamp radiators were not used because of the safety requirement that no form of electricity can be in the general area of live ordnance. Of course, the demonstration used inert filler, but it was necessary to demonstrate a possible solution to the more general case.

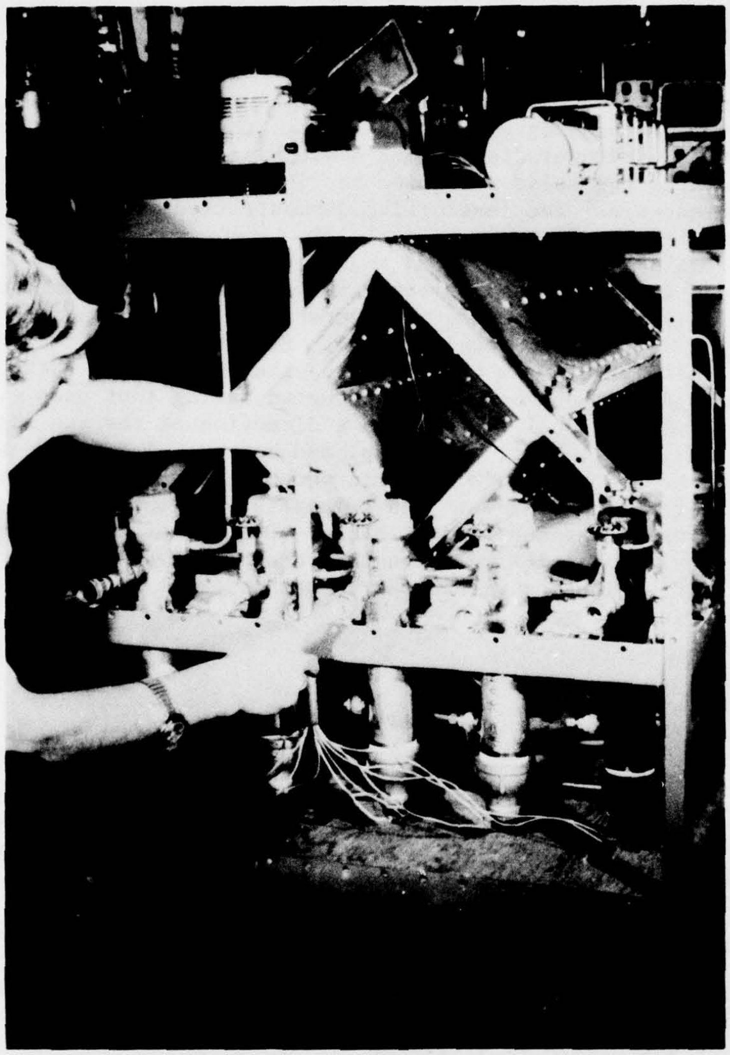

FIGURE 1. Isometric View of Four-Panel Simulation Oven.

Besides the four independently heated panels, there was a similar heater system for air which flowed axially through a small automobile radiator. The radiator was removed so the panels could be seen in the photograph (Figure 1). All five heaters were 1500-watt Cal-rod heaters. The liquid flow rate was 1 gal/min (3.8 l/min). A schematic diagram of one control system is shown in Figure 2. There were five (four panels and air system) identical control systems, the details of which are given in Appendix A.

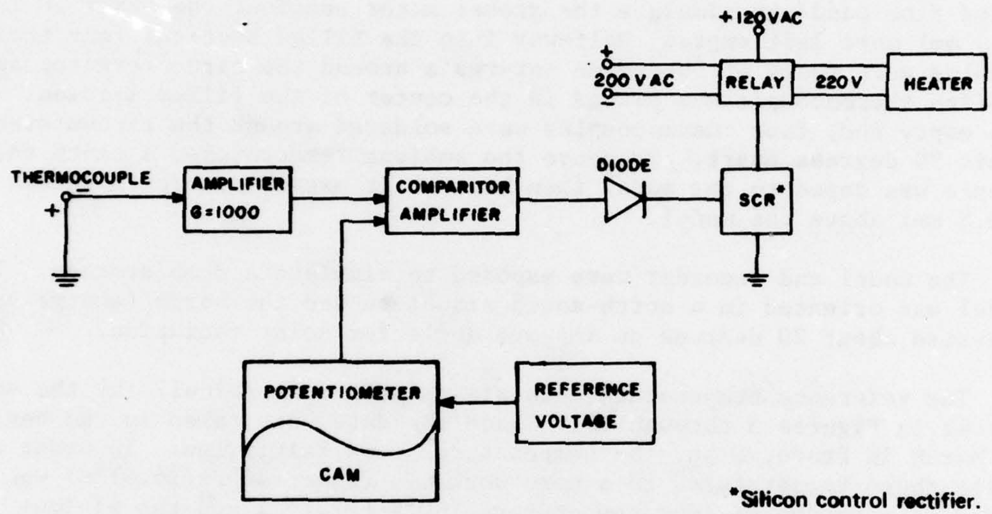

FIGURE 2. Block Diagram of Control System.

Part of the simulated missile was filled with dry sand and the remainder was left empty. The "filled" and "empty" sections simulate the extreme longitudinal density variations which occur in missiles. The high density areas are motor and warhead; the low density areas are the control and guidance sections. It is necessary in any thermal simulation chamber to allow both sections to behave as they would in the real world. This cannot be done by either convection or radiation ovens, but requires a combination of both convection and radiation just as in the real life situation. The reason is that the thermal time constant of response is a function of the physical and thermal properties of each section of the item under test (i.e., missile). With only one mode of heat transfer, and the transferred heat monitored by a single thermocouple affixed to only one representative surface of the missile, other sections will tend to be over or underheated. A small thermal time constant of response unit, such as a thin metal shell with no heat sink, would be much too hot. A large thermal time constant of response unit would hardly be bothered at all by the same heat flow. By adding radiant heat and forced convection, the many different modes of thermal response can and will be activated in the same manner as they are activated in field storage.

COLLECTION OF REFERENCE DATA

An instrumented simulated rocket section and 12-channel recorder were used to collect the reference temperature data. Also, a velometer was used to measure the wind velocity.

The rocket shell was 8 inches (203 mm) in diameter and 30 inches (762 mm) long; 20 inches (508 mm) of which was filled with an oven-dried fine sand[3] to simulate the rocket motor section, the other 10 inches (762 mm) were left empty. Half-way into the filled section, four thermocouples were fused at 90-degree intervals around the circumference, and a fifth thermocouple was placed in the center of the filled section. On the empty end, four thermocouples were soldered around the circumference, again 90 degrees apart. To sense the ambient temperature, a tenth thermocouple was taped to the model then bent so it extended about 2 inches (50.8 mm) above the model.

The model and recorder were exposed to simulate a dump storage. The model was oriented in a north-south situation and the north (empty) end elevated about 20 degrees to improve angle for solar radiation.

The reference temperature data are presented graphically by the solid curves in Figures 3 through 12. Since the data were taken in the beginning of March in Provo, Utah, the temperatures were fairly low. In order to raise these temperatures to a more workable range, 30°F (16.67°C) was added to make the maximum temperature 160°F (71.1°C) and the minimum about 65°F (18.3°C). This eliminated the need for a refrigeration system coupled with the heating system. Future systems will need both heating and cooling.

SIMULATION OVEN TESTING

Test results for each thermocouple location as a function of time of day are presented in graphic form by the dashed curves in Figures 3 through 12. Note that, except for the top and west side of the filled section, all the maximum temperatures on the rocket motor were within 8°F (4.44°C) of the previously measured values in the field.

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[3] Naval Weapons Center. "Measured Temperatures of Solid Rocket Motors Dump Stored in the Tropics and Desert, Part 3. Desert Dump Storage," by H.C. Schafer. China Lake, California, NWC, May 1977. (NWC TP 5039, Part 3, publication UNCLASSIFIED.)

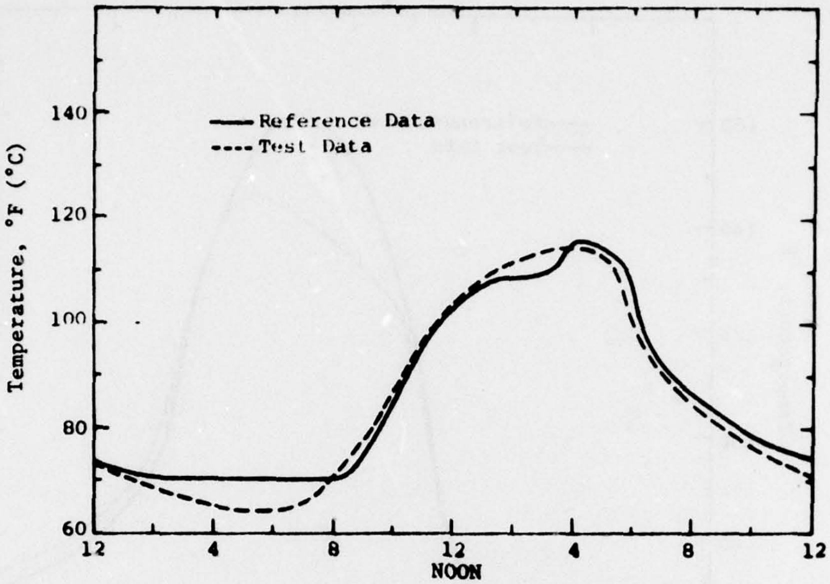

FIGURE 3. Temperature vs. Time of Day For Bottom of Filled Section.

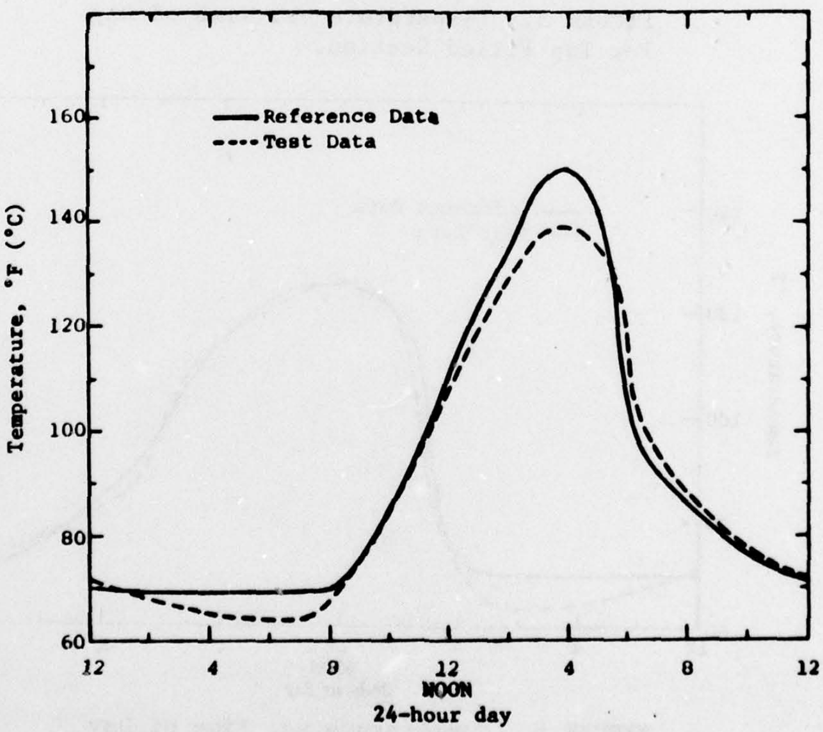

FIGURE 4. Temperature vs. Time of Day For West Filled Section.

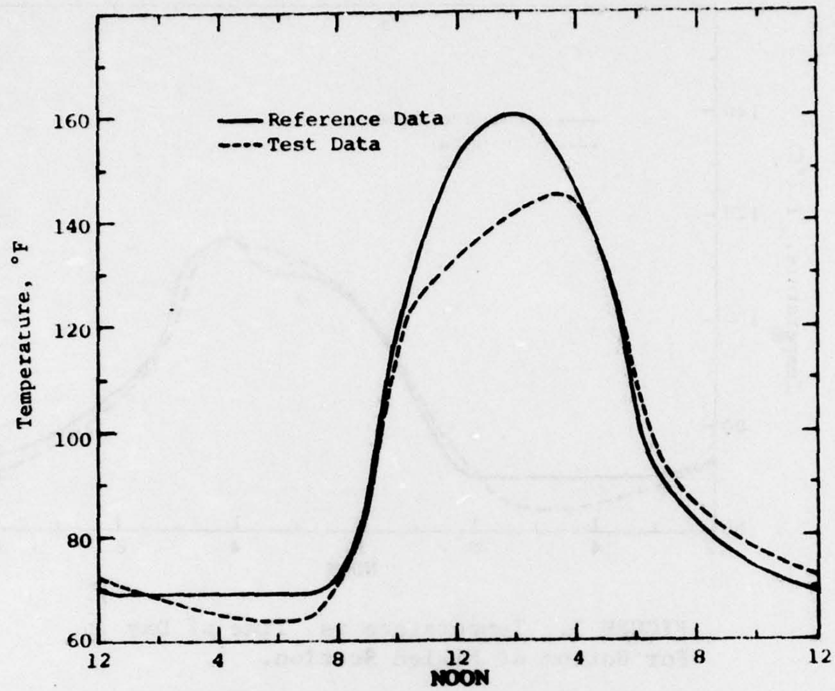

FIGURE 5. Temperature vs. Time of Day For Top Filled Section.

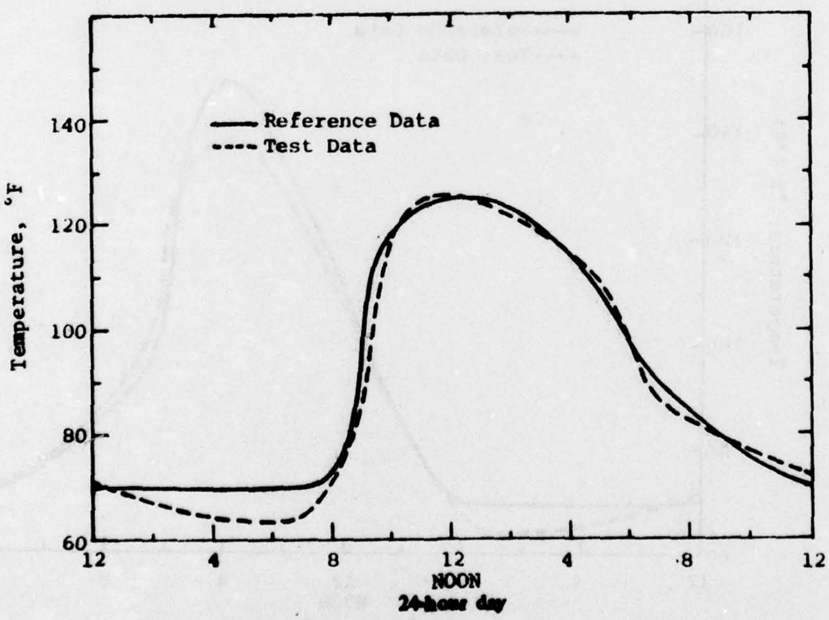

FIGURE 6. Temperature vs. Time of Day For East Filled Section.

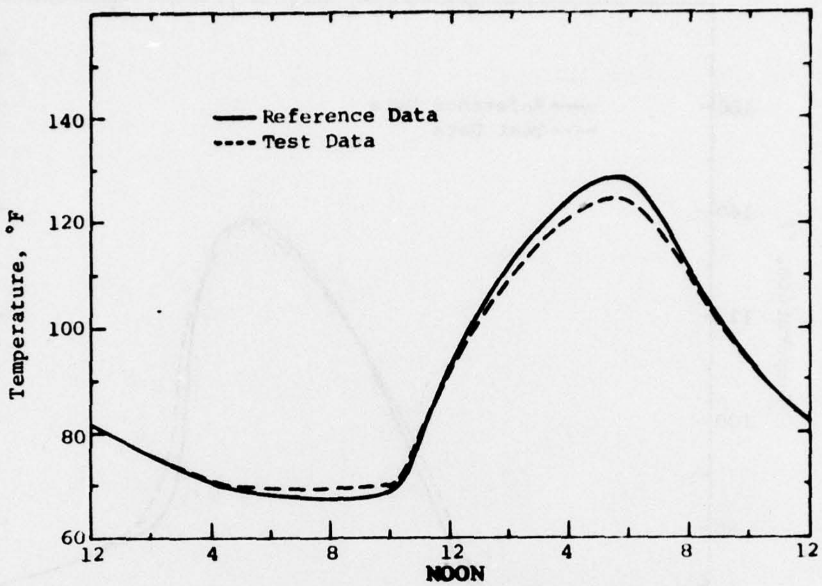

FIGURE 7. Temperature vs. Time of Day For Center Filled Section.

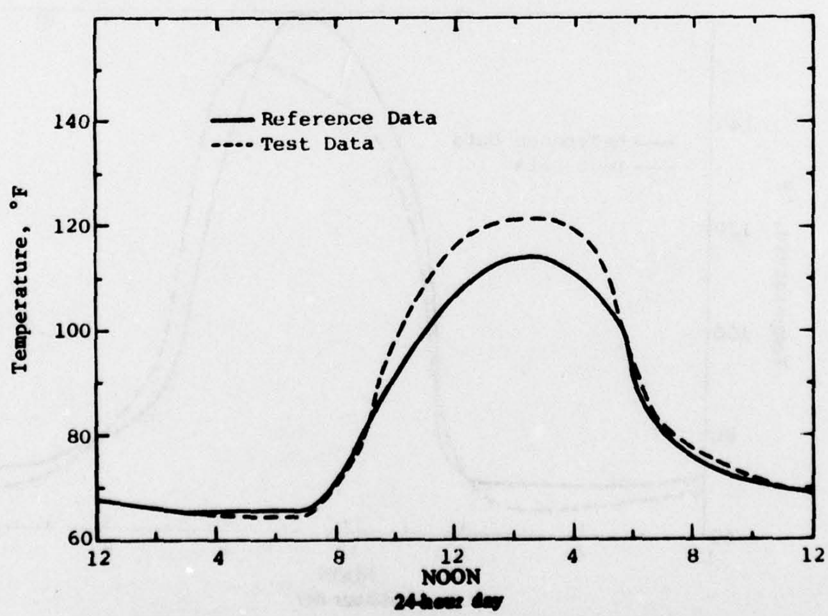

FIGURE 8. Temperature vs. Time of Day For Bottom Empty Section.

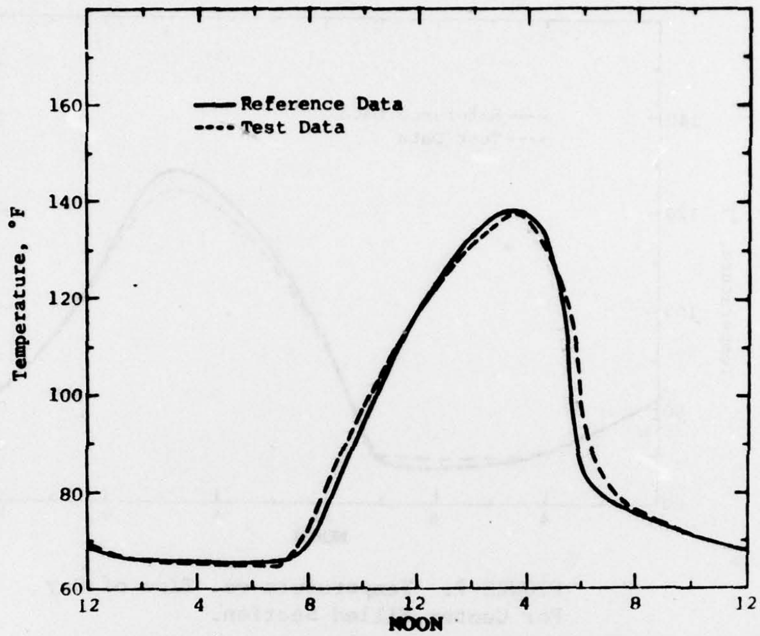

FIGURE 9. Temperature vs. Time of Day
For West Empty Section.

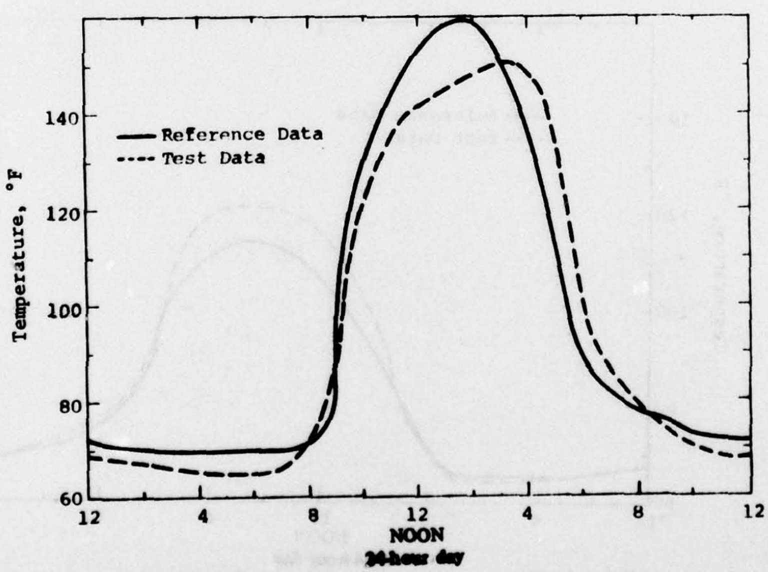

FIGURE 10. Temperature vs. Time of Day
For Top Empty Section.

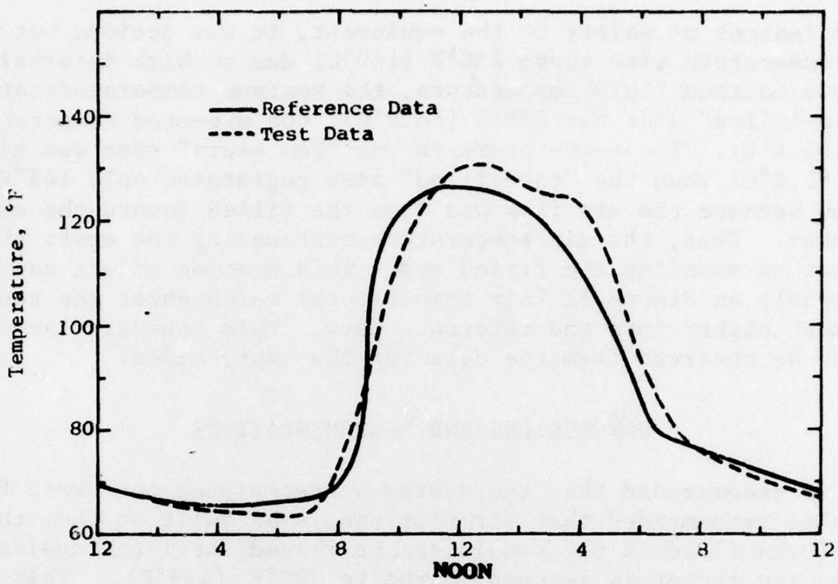

FIGURE 11. Temperature vs. Time of Day For East Empty Section.

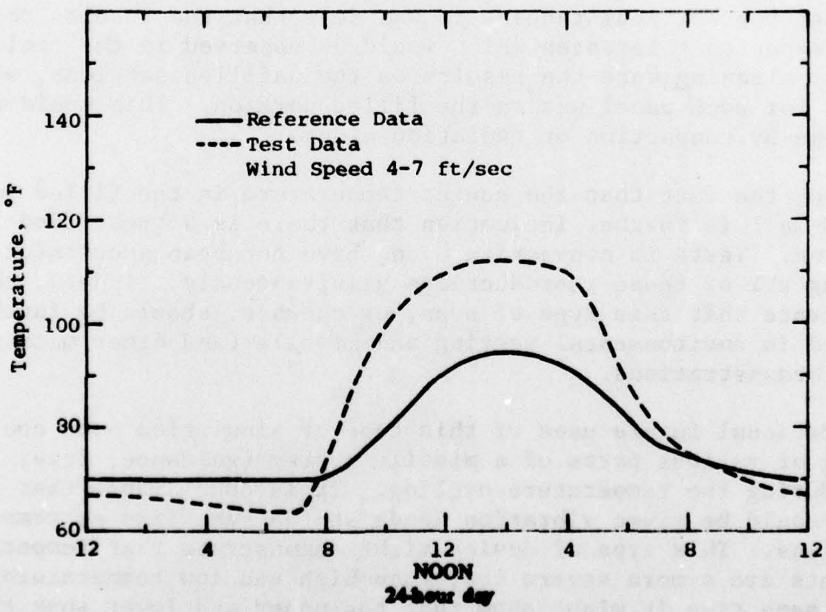

FIGURE 12. Temperature vs. Time of Day For Air Temperature.

For reasons of safety to the equipment, it was decided not to let the fluid temperature rise above 230°F (110°C) due to high internal pressures. With this maximum fluid temperature, the maximum temperature attained by the "top-filled" side was 138°F (58.9°C); the expected temperature was 150°F (65.6°C). The temperature on the "top empty" side was higher than 145°F (62.8°C) when the "top-filled" side registered only 145°F (62.8°C). This was because the air flow was from the filled toward the empty end of the rocket. Thus, the air temperature surrounding the empty end was higher than that surrounding the filled end. This heating effect can be noted more clearly on Figure 12 (air temperature) which shows the test temperature much higher than the reference data. This boundary layer influence can also be observed from the data for the empty sides.

CONCLUSIONS AND RECOMMENDATIONS

It is recommended that the system be redesigned for cross flow of air. It is also recommended that stronger panels be built so that the temperature of the fluid in the panels can be raised until the desired temperature in the rocket is reached, maybe to 300°F (419°C). This might also be accomplished by using a low pressure oil. There were some coupling effects between the circuits which may have been due to the high gain (1,000) of the amplifier. The problem may be solved by using two amplifiers in series.

Under these circumstances, it was felt that the results were well within expected tolerances which would be observed in the field. Especially pleasing were the results on the unfilled sections, while the control for each panel was on the filled portion. This could not have been done by convection or radiation alone.

Also, the fact that the center temperature in the filled portion tracked well is further indication that there is a great need for this type oven. Tests in convection ovens have not been successful in accomplishing all of these reproductions simultaneously. Indeed, these results demonstrate that this type of oven, or chamber, should be further developed and used in environmental testing and missile (and other material) qualification demonstrations.

Additional future uses of this type of simulation oven could allow testing of various parts of a missile system (guidance, fuse, igniters, etc.) during the temperature cycling. It is conceivable that the missile system could be given vibration loads at the same time as temperature variations. This type of device might demonstrate that temperature gradients are a more severe test than high and low temperature soak. At the same time it might show that the upper and lower soak temperature limits may be too severe. The projected cost for such an oven is low enough that live ordnance could be tested and assume the risk of misfire damaging the equipment. Indeed, the future uses of this concept are only limited by the imagination of environmental sumulation engineers.

Based on the results of this work the following conclusions may be drawn:

1. Local surface temperatures can be made to follow the same time path in an oven as they do outdoors, even with a relatively simple, low cost, system.

2. The unfilled portion of the missile followed its respective outdoor conditions in the oven even though it was not controlled.

3. When all the surface temperatures follow their proper paths, the internal temperatures follow their respective paths, as indicated by the center thermocouple data.

4. The feasibility of this new type of environmental simulation oven has been demonstrated by this relatively simple oven.

Appendix A

DESIGN CONSIDERATIONS

AMPLIFIER GAIN

Since the output of a thermocouple is on the order of millivolts and volts are preferred for ease of handling, the gain of the amplifier should be 1000. This gain is set by the ratio of the resistors R_2 to R_1 in Figure A-1.

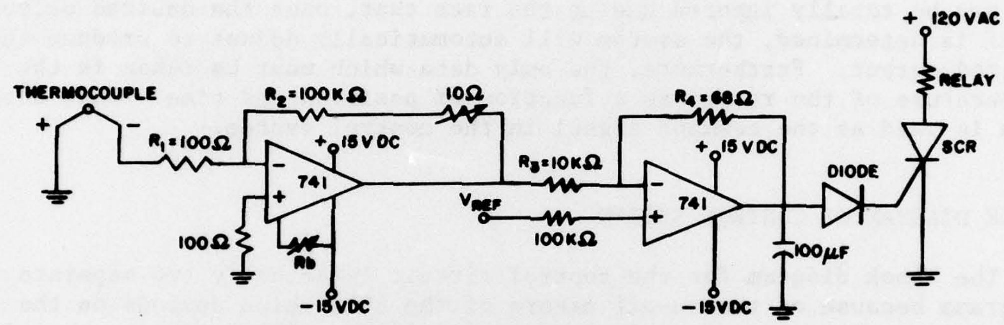

FIGURE A-1. - Detailed Electric Circuit Diagram.

HEAT SOURCE

Current oven safety regulations do not allow electrical heating with live ordnance due to the possibility of sparks and explosions. This led to the heated liquid systems.

HEATER CAPACITY

Assuming the heat loss per panel to be 450 BTU/hr, it was recognized that the heating element in the reservior must supply at least 450 BTU/hr. For this purpose an ordinary waterheater heating element (CHROMALOX 6001A, rated at 1500 watts with 220 VAC) was chosen.

FLOW RATE AND PUMP SELECTION

By assuming the heat radiated and convected by each panel to be 450 BTU/hr, we were able to calculate the volume of flow to be 0.25 gal/min (0.9 l/min). This is a very small flow rate; but, by increasing it, the

temperature drop across the panel will be decreased. Therefore, a positive displacement gear pump was chosen which has a flow rate of 1.3 gal/min (4.9 l/min) at 1200 rpm and 20 psi. Circumstances demanded that a larger pump (2.5 gal/min (9.5 l/min) at 1200 rpm and 20 psi) be employed on two of the heating panels. Each pump, at the specified rating, required a 1/6 hp motor rated at least 1200 rpm. On this project, two 1/4 hp motors rated at 1725 rpm were employed with each driving a small and a larger pump.

CONTROL SYSTEM

With closed-loop control, the non-linearity of radiation heat transfer may be totally ignored due to the fact that, once the desired output level is determined, the system will automatically adjust to produce the desired output. Furthermore, the only data which must be taken is the temperature of the rocket as a function of position and time. This data then is used as the command signal in the control system.

BLOCK DIAGRAM OF CONTROL SYSTEM

The block diagram for the control circuit is actually two separate diagrams because of the on-off nature of the SCR, which depends on the gate voltage ($v_{ref} - v_t$), polarity and magnitude. Thus, if $v_{ref} - v_t$ is greater than +1.4 volts, the diagram is that which appears in Figure A-2. If, however, the gate voltage is less than 1.4 volts, the diagram is that which appears in Figure A-3. The quantity, q_L, represents the total power to the load and equals heat due to convection from the heating panels to ambient plus net heat due to radiation from the panels to the rocket.

T_{ref} represents the desired output of the system and T_t represents the actual output. The reference temperature, T_{ref}, is then converted to a voltage. The "on-off" or "proportional switch" represents an SCR which triggers and allows current to flow in the heater.

The feedback loop consists of the thermocouple which senses the temperature and a voltage amplifier which amplifies the thermocouple voltage to a workable range.

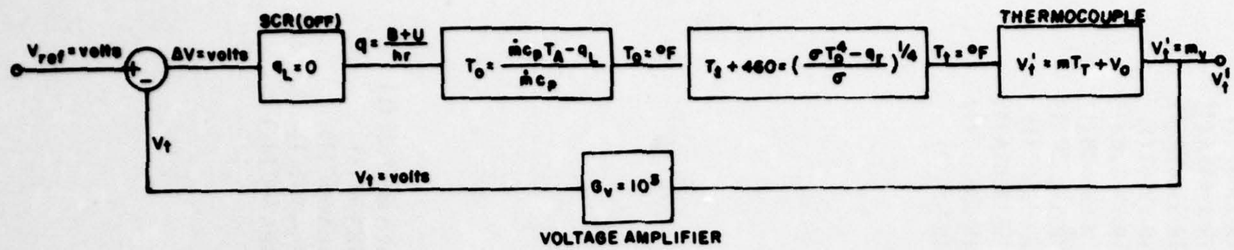

FIGURE A-2. - Control Block Diagram When SCR Is Off $(q_L = 0)$

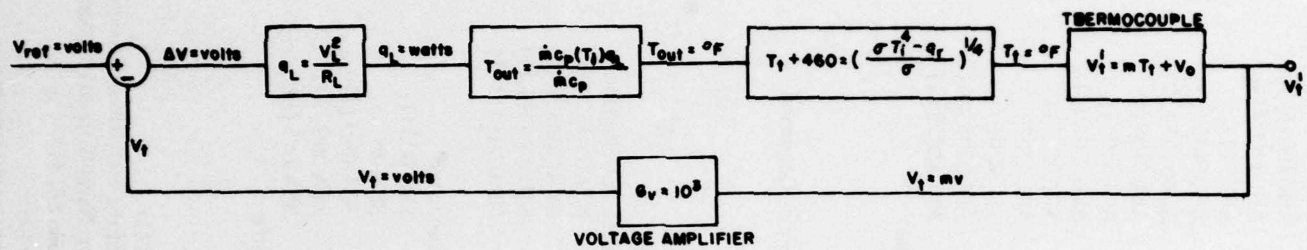

FIGURE A-3. - Control Block Diagram When SCR Is On $\left(q_L = \frac{V_L^2}{R_L}\right)$

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- SEA-00E (1)
- SEA-03 (1)
- SEA-03B (1)
- SEA-0331 (1)
- SEA-033 (1)
- SEA-06 (1)
- SEA-06M (1)
- SEA-09G32 (2)
- SEA-653 (1)
- SEA-6531D (1)
- SEA-654 (1)
- SEA-6543C (1)
- SEA-660M (1)
- SEA-660T (1)
- SEA-661D-22 (1)
- SEA-98 (1)
- SEA-98C (1)
- SEA-982 (1)
- SEA-9821 (1)

4 Chief of Naval Research
- ONR-100 (1)
- ONR-200 (1)
- Code 411-6 (1)
- Technical Library (1)

1 Assistant Secretary of the Navy (Research and Development)

2 Fleet Analysis Center, Naval Weapons Station, Seal Beach
- GIDEP Office, Code 862 (1)
- Technical Library (1)

4 Naval Air Engineering Center, Lakehurst
- Code 93 (1)
- D. Broude (1)
- Technical Library (2)

2 Naval Air Test Center (CT-176), Patuxent River (Technical Library)
2 Naval Ammunition Depot, Earle (Technical Library)
2 Naval Avionics Center, Indianapolis
R. D. Stone (1)
Technical Library (1)
2 Naval Ocean Systems Center, San Diego
Code 133 (1)
Code 603 (1)
26 Naval Ordnance Station, Indian Head
Code EST, A. T. Camp (1)
Code FSC (1)
Code FS11C (1)
Code FS12A1 (1)
Code FS12A2 (1)
Code FS12A6 (1)
Code FS12B (1)
Code FS12D (1)
Code FS13, G. A. Bornstein (1)
Code FS13A (1)
Code FS13C (1)
Code FS14 (1)
Code FS15A (1)
Code FS15B (1)
Code FS42 (1)
Code FS63 (1)
Code FS64 (1)
Code FS72 (1)
Code QA (1)
Code QA3 (1)
Code 5A (1)
Code 5712A (1)
Code 611, A. P. Allen (1)
J. Wiggin (1)
Technical Library (2)
1 Naval Postgraduate School, Monterey (Technical Library)
2 Naval Research Laboratory
R. Volin (1)
Technical Library (1)
4 Naval Ship Engineering Center, Hyattsville
Code 6100 (1)
Code 6105B (1)
Code 6181B (1)
Technical Library (1)
10 Naval Surface Weapons Center, Dahlgren Laboratory, Dahlgren
Code T (1)
Code TI, Jim Hurtt (2)
Code WXO (1)
Code WXR (1)
Code WXS (1)
Code WXT (1)
Code WXV (1)
Jim Horten (1)
Technical Library (1)
4 Naval Surface Weapons Center, White Oak
Code 702
C. V. Vickers (1)
V. Yarow (1)
Code KM (1)
Technical Library (1)
2 Naval Weapons Evaluation Facility, Kirtland Air Force Base
APM-4, G. V. Binns (1)
Technical Library (1)
2 Naval Weapons Quality Assurance Office
Director (1)
Technical Library (1)

1 Naval Weapons Station, Concord (Technical Library)
5 Naval Weapons Station, Seal Beach
  Environmental Test Branch (1)
  QE Department (1)
  Code QESX (1)
  Technical Library (1)
  T. B. Linton (1)
2 Naval Weapons Station, Yorktown
  Code 3032, Smith (1)
  Technical Library (1)
4 Naval Weapons Support Center, Crane
  NAPEC, J. R. Stokinger (1)
  Code RD (1)
  Code QETE (1)
  Technical Library (1)
10 Pacific Missile Test Center, Point Mugu
  Code 5300 (1)
  Code 5711, Sparrow (1)
  Code 5714, Flartey (1)
  Code 5718, F. J. Brennan (1)
  Technical Library (1)
  T. Elliott (1)
  L. Matthews (1)
  E. P. Olsen (1)
  C. V. Ryden (1)
  R. W. Villers (1)
3 Office Chief of Research and Development
  Dr. Leo Alpert (1)
  Environmental Sciences Division (1)
  Technical Library (1)
2 Army Armament Materiel Readiness Command, Rock Island
  Director, Laboratories Division (1)
  Technical Library (1)
2 Army Aviation Research and Development Command
  Technical Director (1)
  Technical Library (1)
3 Army Electronics Command
  Director Electronic Laboratory (1)
  Director Research and Development, AMSEL-RD (1)
  Technical Documents Center (1)
16 Army Materiel Development and Readiness Command
  DRCBI-L (1)
  DRCDE (1)
  DRCDE-D (1)
  DRCDE-R (1)
  DRCMT (1)
  DRCPA-E (1)
  DRCPA-S (1)
  DRCPM-HA (1)
  DRCPM-LC (1)
  DRCPM-MP (1)
  DRCPM-PBM-LN1 (1)
  DRCPM-RK (1)
  DRCPM-SHO (1)
  DRCSF-E (1)
  DRSMI, J. Taylor (1)
  Technical Library (2)
2 Army Tank Automotive Research and Development Command
  Technical Director (1)
  Technical Library (1)
1 Army Training and Doctrine Command (ATCD-T)

17 Aberdeen Proving Ground
AMSTE-TA
Goddard (1)
Peterson (1)
DRSTE-ME (2)
DRXBR-XA-LB (1)
SGRD-UBG (1)
STEAP-DS (1)
STEAP-MT (1)
STEAP-MT-A (1)
STEAP-MT-G (1)
STEAP-MT-M, J. A. Feroli (1)
STEAP-MT-O (1)
STEAP-MT-K (1)
STEAP-MT-5 (1)
STEAP-SA (1)
Dr. Sperrazza, AMSAA (1)
Technical Library (1)

4 Army Ammunition Center, Savannah
Artillery Division (1)
Small Arms Division (1)
Technical Library (2)

1 Army Chemical Research and Development Laboratories, Edgewood Arsenal (Technical Library)

4 Army Chemical Warfare Laboratories, Edgewood Arsenal (Technical Library)

4 Army Engineer Topographic Laboratories, Fort Belvoir
ETL-GS-EA (1)
ETL-GS-EC, H. McPhilimy (2)
Technical Library (1)

3 Army Operations Test and Evaluation Agency, Aberdeen Proving Ground
Technical Director (1)
CSTE-PRP (1)
Technical Library (1)

3 Army Tropic Test Center
MET Team (1)
Pacific Test Branch (1)
Technical Library (1)

1 Army 14th Aviation Unit, Graf Detachment (SF-4 K. R. S. Polley)

1 Fort Huachuca (CC-OPS-SM)

1 Fort McPherson (AFOP-DA)

4 Harry Diamond Laboratories
Technical Director (1)
R. Hoff (1)
R. Smith (1)
Technical Library (1)

17 Army Armament Research and Development Center
DRDAR-PM, Bethel (1)
DRDAR-LCU-TD, P. Korman (1)
SMUPA-AD-S, W. J. Ryan (1)
SMUPA-CO-T (1)
SMUPA-ND, J. Hasko (1)
SMUPA-TS-E (1)
Small Arms Development Office (2)
Small Caliber Weapons Systems Lab (1)
D. Askin (1)
G. Bate (1)
G. H. Bornheim (1)
M. Resnick (1)
A. Cogliocci (1)
V. T. Riedinger (1)
Technical Library (2)

7 White Sands Missile Range
Director Electromechanical Laboratories (1)
Environmental Laboratories (1)
QSTEWS-RE-F, Fergig (1)
STEWS-TE-MF (1)
STEWS-TE-P (1)
J. McDougal (1)
Technical Library (1)

4 Yuma Proving Ground
- W. Brooks (1)
- K. O. Gietzen (1)
- L. Pendelton (1)
- Technical Library (1)

3 Headquarters, U.S. Air Force
- AFRDC (1)
- AFRDPS, Allen Eaffy (1)
- Technical Library (1)

9 Air Force Systems Command, Andrews Air Force Base
- DL (1)
- LG (1)
- SD (1)
- TE (1)
- XR (1)
- XRLW, Col. Melichor (1)
- LCol. T. Hill (2)
- Technical Library (1)

6 Tactical Air Command, Langley Air Force Base
- TAC-DR (1)
- TAC-LG (1)
- TAC-LGM (1)
- TAC-LGS (1)
- TAC-LGW (1)
- Technical Library (1)

14 Ogden Air Materiel Area, Hill Air Force Base
- DSTCM, J. R. Bennett (1)
- DSY (1)
- DSTS (1)
- MAK (1)
- MM (1)
- MME (1)
- MMECM (1)
- MMJ (1)
- MMW (1)
- MMS (1)
- OOYIT (1)
- SE (1)
- Munitions Safety (1)
- Technical Library (1)

12 Oklahoma City Air Materiel Area, Tinker Air Force Base
- DSY (1)
- DSYS (1)
- MAG (1)
- MAI (1)
- MAK (1)
- MM (1)
- MMC (1)
- MME (1)
- MMEC (1)
- MMN (1)
- MMS (1)
- OC-ALC (1)

11 Sacramento Air Materiel Area, McClellan Air Force Base
- MM (1)
- MMA (1)
- MMB (1)
- MMC (1)
- MME (1)
- MMEM, J. Phillips (1)
- MMH (1)
- MMJ (1)
- MMN (1)
- MMS (1)
- Technical Library (1)

9 Warner Robins Air Materiel Area, Robins Air Force Base
- DSD (1)
- MA (1)
- MAB (1)
- MAI (1)
- MM (1)
- MMA (1)
- MME (1)
- MMS (1)
- Technical Library (1)

4 Strategic Air Command, Offutt Air Force Base
- DO (1)
- DR (1)
- LG (1)
- Technical Library (1)

26 Aeronautical Systems Division, Wright-Patterson Air Force Base
Director of Flight Dynamics Laboratory (1)

AE (1)	ENF (1)	SD65 (1)	YPT (1)
AEA (1)	ENS (1)	YF (1)	YX (1)
AER (1)	FEE (3)	YSL (1)	YXL (1)
EN (1)	PP (1)	YFT (1)	YXT (1)
ENA (1)	SD (1)	YP (1)	
ENE (1)	SD25 (1)	YPL (1)	

1 Air Force Avionics Laboratory, Wright-Patterson Air Force Base
1 Air Force Cambridge Research Laboratories, Laurence G. Hanscom Field (Technical Library)
1 Air Force Environmental Technical Applications Center (Technical Library)
1 Air Force Office of Scientific Research (Dr. J. F. Masi)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Technical Director)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Plans and Programs Office)
2 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (RKMA, L. Meyer)
1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Technical Library)
23 Armament Development and Test Center, Eglin Air Force Base

DL (1)	DLY (1)	SD9 (1)
DLA (1)	SD (1)	SDMT
DLB (1)	SD102 (1)	Carley (1)
DLD (1)	SD15 (1)	Holcomb (1)
DLJ (1)	SD2 (1)	Volz (1)
DLM (1)	SD23 (1)	TE (2)
DLO (1)	SD3 (1)	Technical Library (1)
DL-1 (1)	SD7 (1)	

1 Nellis Air Force Base (Technical Library)
2 Rome Air Development Center, Griffiss Air Force Base
Code RCRM (1)
Technical Library (1)
3 Assistant Secretary of Defense
DMSSO, J. Allen (1)
F. W. Myers (1)
Explosives Safety Board (1)
7 Director of Defense Research and Engineering
AD(ET) G. R. Makepeace (1)
OAD(ET) R. Thorkildsen (1)
US od D(SS) Col. B. Swett (2)
DD(T&E) (1)
AMRAD Committee (2)
1 Defense Advanced Research Projects Agency, Arlington (Technical Library)
12 Defense Documentation Center
2 Joint Chiefs of Staff
Standards Branch (1)
Technical Library (1)
3 Library of Congress
1 Aerojet-General Corporation, Azusa, CA (Technical Library)
2 Aerojet Liquid Rocket Company, Sacramento, CA (via AFPRO) (Technical Library)
1 Allegany Ballistics Laboratory, Cumberland, MD (Technical Library)
1 Applied Physics Laboratory, Johns Hopkins University, Laurel, MD (Technical Library)
1 ARINC Research Corporation, Santa Ana, CA

2 Bell Aerospace Textron, Dallas, TX
  Technical Library (1)
  D. L. Kidd (1)
1 Bemco, Inc., Pacoima, CA (John Riddle)
1 Blue M Electric Company, Blue Island, IL (Joseph A. Lawler)
1 Booze Allen, Bethesda, MD
2 Chemical Propulsion Information Agency, Applied Physics Laboratory, Laurel, MD
  Sid Solomon (1)
  Technical Library (1)
1 Dayton T. Brown, Inc., Bohemia, LI, NY (Technical Library)
1 Eastman Kodak Company, Kodak Apparatus Division, Rochester, NY (Dr. David R. Simonsen)
1 Endevco-Dynamic Instrument Division of Becton, Dickinson Company, San Juan Capistrano, CA (Jon S. Wilson)
2 Ford Aerospace and Communications Corporation, Newport Beach, CA
  R. Elston (1)
  Technical Library (1)
1 General Dynamics, Pomona Division, Pomona, CA (Technical Library)
1 Genrad, Inc., Time Data Division, Santa Clara, CA (Dan L. Woodward)
1 Hercules, Inc., Bacchus Works, Magna, UT
1 Hercules, Inc., McGregor, TX (Technical Library)
1 Hewlett-Packard Company, Santa Clara, CA (Johnathon R. Cross)
1 Hughes Aircraft Company, Canoga Park, CA (Technical Library)
1 Hughes Aircraft Company, Culver City, CA (Richard L. Baker)
2 Institute of Environmental Sciences, Mt. Prospect, IL
1 Kimball Industries, Inc., Monrovia, CA (David V. Kimball)
1 Ling Electronics, Anaheim, CA (J. D. Monk)
2 Lockheed Aircraft Corporation, Marietta, GA
  Technical Library (1)
  E. H. Parker (1)
1 Lockheed-California Company, Burbank, CA
1 McDonnell Douglas Astronautics, Huntington Beach, CA
1 McDonnell Douglas Corporation, Long Beach, CA (Technical Library)
1 McDonnell Douglas Corporation, Santa Monica, CA
5 McDonnell Douglas Corporation, St. Louis, MO
  Aircraft Division, Technical Library (1)
  Harpoon Project Office (1)
  Missile Division Technical Library (1)
  B. Dighton (1)
  GIDEP Rep. (1)
1 Marquardt Corporation, Van Nuys, CA
2 Martin Marietta Company, Denver, CO
  Reliability (1)
  Technical Library (1)
2 Martin Marietta Corporation, Orlando, FL
  Engineering Library MP-30 (1)
  Technical Library (1)
1 Nicolet Scientific Corporation, Northvale, NJ (George Lang)
2 North American Rockwell Corporation, Columbus, OH
  Engineering Development Laboratories (1)
  Technical Library (1)

1 Northrop Corporation, Los Angeles, CA (David A. Bond)
1 Raytheon Company, Waltham, MA (Technical Library)
1 Rockwell International Corporation, Los Angeles, CA (Technical Library)
1 Rohm and Haas Company, Huntsville, AL
3 Sandia Corporation, Albuquerque, NM
    Section 1541, Jerry T. Foley (2)
    Section 1543, Mark B. Gens (1)
3 Sandia Corporation, Livermore, CA
    C. A. Scott (2)
    Technical Library (1)
1 Spectral Dynamics Corporation of San Diego, San Diego, CA (A. C. Keller)
1 Team Corporation, South El Monte, CA (William P. Artz)
1 Tenney Engineering, Inc., Union, NJ (Martin S. Schletter)
1 Texas Instruments, Inc., Dallas, TX (Technical Library)
5 The Boeing Company, Seattle, WA
    S. Barber, MS 8609 (1)
    J. P. Stebbins (1)
    F. P. Stevens, Standards Control (1)
    J. Stuart, MS 47-06 (1)
    Technical Library (1)
1 Thermotron Corporation, Holland, MI (Charles F. Conrad)
1 Thiokol Chemical Corporation, Newtown, PA
1 Thiokol Chemical Corporation, Wasatch Division, Brigham City, UT
1 Unholtz-Dickie Corporation, Hamden, CT (Karl Unholtz)
1 United Technologies, Chemical Systems Division, Sunnyvale, CA
1 Value Engineering Company, Alexandria, VA (J. Toomey)
3 Vought Corporation, Systems Division, Dallas, TX
    R. N. Hancock, Unit 2-53483 (2)
    Technical Library (1)
1 Westinghouse Defense and Space Center, Baltimore, MD (Victor D. Marone)
1 Wyle Laboratories, El Segundo, CA (Paul M. Turkheimer)